cause of high development costs which are amortized over a few targets, in contrast with a greater non-laser expenditure per target killed, but with lesser development cost.

Direct Sea-to-Air Refueling of Aircraft (DSTAR)

The topics discussed thus far, with the exception of high-energy lasers, are necessarily selected from a larger set important to future American military capability. They bear no necessary relationship to the present emphases of Defense Department programs, although their elements are largely present if unemphasized. The author has recommended that such current programs as the B-1 bomber and the Trident submarine (and certain advanced tactical aircraft and support programs) should be *replaced* by programs such as those discussed above.

But modern electronics and control technology, in combination with existing systems, can have other far-reaching impacts on American capabilities. For instance, they can offset the reluctance of allies or neutrals to provide refueling bases for American combat and military cargo aircraft. Briefly, a system can be developed which will permit an aircraft to refuel from a ship at sea in five or ten minutes. An aircraft as small as an F-4 or as large as a C-5 can receive fuel pumped through a hose which links a tanker ship to an aircraft circling at perhaps 1,000 meters distance and 300 meters altitude. A modest 50,000 ton tanker can refuel 500 C-5 flights or 5,000 F-4 sorties, at a cost far below that for providing tanker aircraft on station for air-to-air refueling. This system has been dubbed DSTAR (for "direct sea-to-air refueling") and is described briefly below (and more extensively in Ref. 6).

Even under normal circumstances, consideration of range-payload tradeoffs, vehicle productivity, and general utilization of capital might drive one toward the use of ordinary seaborne tankers for refueling fully-loaded cargo (or even passenger) aircraft. Thus, while the C-5 full payload is 220,000 pounds with a range of 3,000 miles, at 5,500-mile range its payload capacity is reduced to 100,000 pounds. DSTAR could more than double the transport capacity of a fleet of C-5s; its effect on an aircraft designed specifically for DSTAR could be greater.

For supply of American military and allies, it is even more important to be able to refuel enroute. During the "October War" of 1973, Air Force Military Airlift Command (MAC) aircraft did not, and could not, land and refuel at NATO bases

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6. Condensed from Document JSR 75-9, ("DSTAR"—Direct Sea-to-Air Refueling) by R. L. Garwin, June 1976, available from National Technical Information Service, Washington.

while carrying material from the United States to Israel. As is well known, we did use the Azores, without which our effort would have been severely impeded.

Even if allied bases were freely available to the United States, the price that has to be paid for continuing access to these bases might be much reduced if there were a practical alternative to continuing use of the bases.

All in all, I would characterize the need for an at-sea in-flight refueling capability as something between urgent and critical.

In-flight at-sea refueling as described here requires an aircraft to fly in a tight pylon turn centered on a normal tanker vessel of small-to-intermediate size equipped with a small amount of specialized equipment. The aircraft is minimally modified, without a winch on board, and is connected by a hose of substantial diameter to a short mast on the tanker. A nominal "drink" duration of five minutes is quite feasible.

Approximate design considerations lead to DSTAR characteristics for two aircraft types as shown in Table 2.

The data for Table 2 are calculated for aircraft on special autopilot at a bank angle of about 45 degrees and at a speed 20 percent above safe landing speed which, in turn, is 20 percent above stall speed.

An aircraft may prepare for refueling by "snatching" a leader line stretched between two light masts on the ship and entering the refueling orbit. A light servo-controlled winch on the ship would maintain tension on the light line until the aircraft achieved a stable orbit, at which time a heavier servo-winch would take over, maintaining constant tension in the range of 12 tons for a C-5 or 1.4 ton for a fighter aircraft. The refueling hose would then be paid out along the leader line, entering a refueling socket in the aircraft. In five minutes, the aircraft tanks would be filled with fuel, the hose disconnected and withdrawn along the leader line. The aircraft would then fly over the ship once more, allowing the leader line to be

Table 2
DSTAR Parameters for Two Aircraft Types (5-Minute Refueling Time)

Aircraft Type	Refueling Orbit		Hose				
	Radius	Altitude	Weight	Tension	Diameter	Pressure	Air Drag
C-5	500 m	300 m	6.0 ton	12 ton	10 cm	1500 psi	2 ton*
F-4	500 m	300 m	0.7 ton	1.4 ton	5 cm	1500 psi	1*-0.1**ton

*Cylindrical (un-faired) hose.
**Faired (streamlined) hose; drag coefficient 0.1.

stowed in the winch for immediate reuse. Such a system could also be set up on land to refuel aircraft where no suitable landing field exists.

It appears desirable and feasible to develop immediately such a capability to re-fuel slightly modified aircraft, of sizes ranging from 50,000 pound fighters to the largest 700,000 pound cargo craft, from tankers underway at sea. Major benefits would accrue to United States military posture and to our position in negotiating access to facilities in allied nations.